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(54) **LUBRICANTS COMPRISING FLUORINATED GRAPHENE NANORIBBONS FOR MAGNETIC RECORDING MEDIA STRUCTURE**

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G11B 5/725 (2006.01)

(52) **U.S. Cl.**
CPC ***G11B 5/725*** (2013.01)

(58) **Field of Classification Search**
CPC G11B 5/72
See application file for complete search history.

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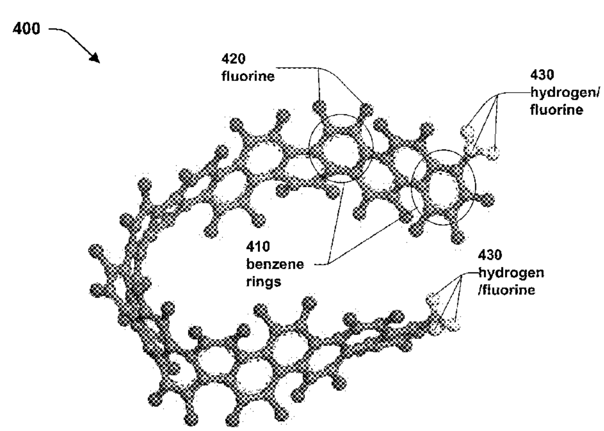
(57) **ABSTRACT**

A novel lubricant comprising a fluorinated graphene nanoribbon for a magnetic recording media structure is disclosed. The magnetic recording media structure includes a substrate, a magnetic recording layer for recording information disposed over the substrate, a protective overcoat layer for protecting the magnetic recording layer disposed over the magnetic recording layer, and a lubricant layer disposed over the protective overcoat layer and comprising a fluorinated graphene nanoribbon.

10 Claims, 6 Drawing Sheets



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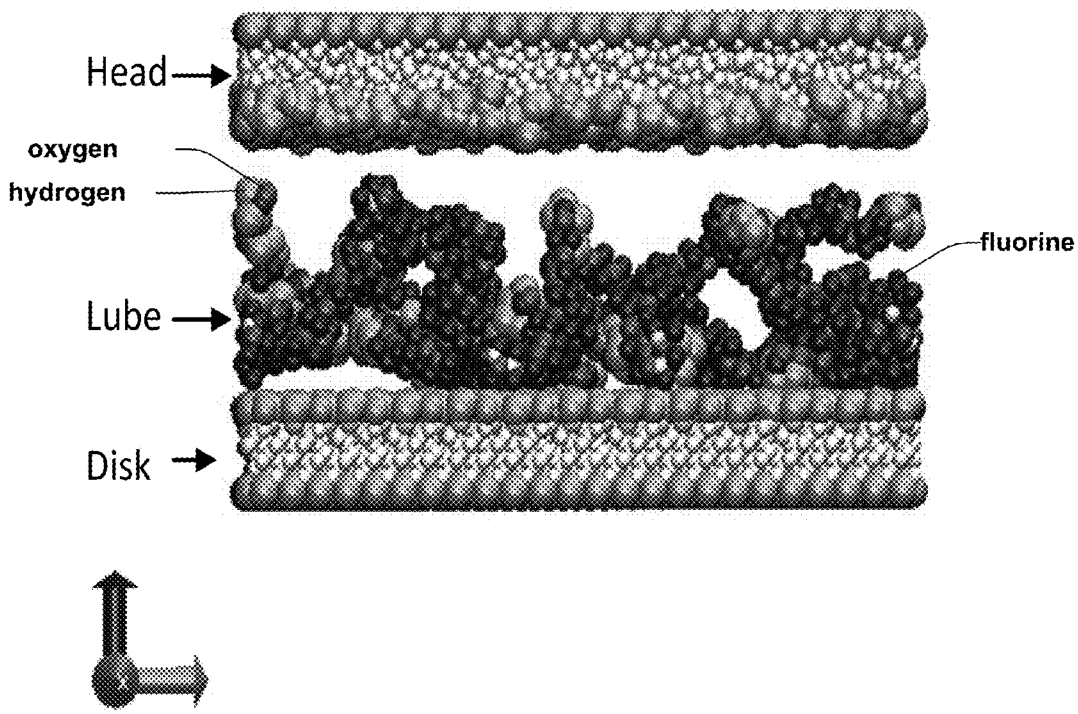

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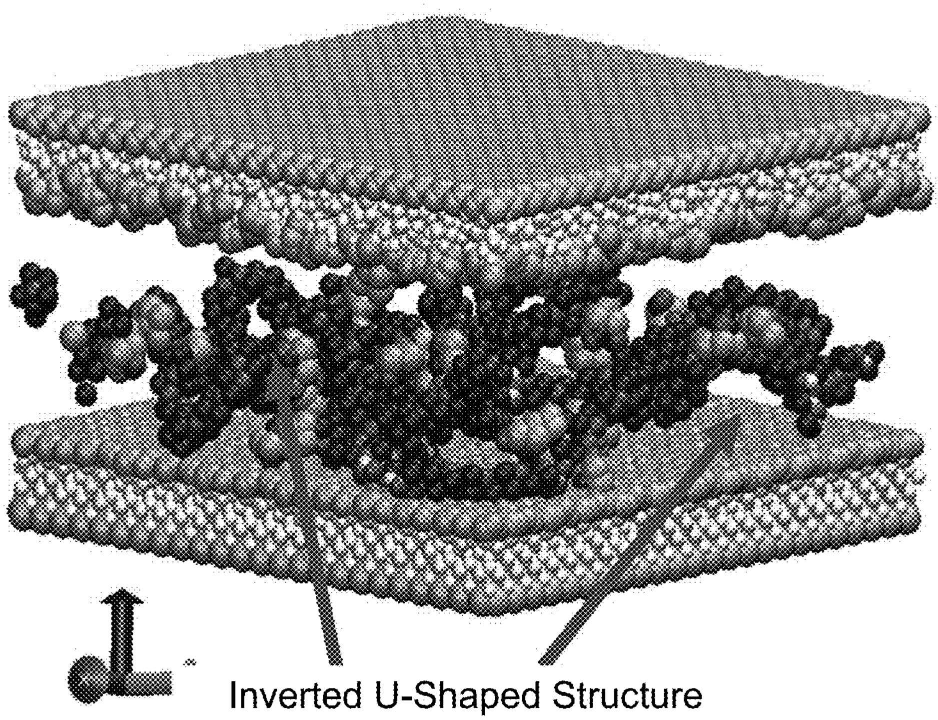

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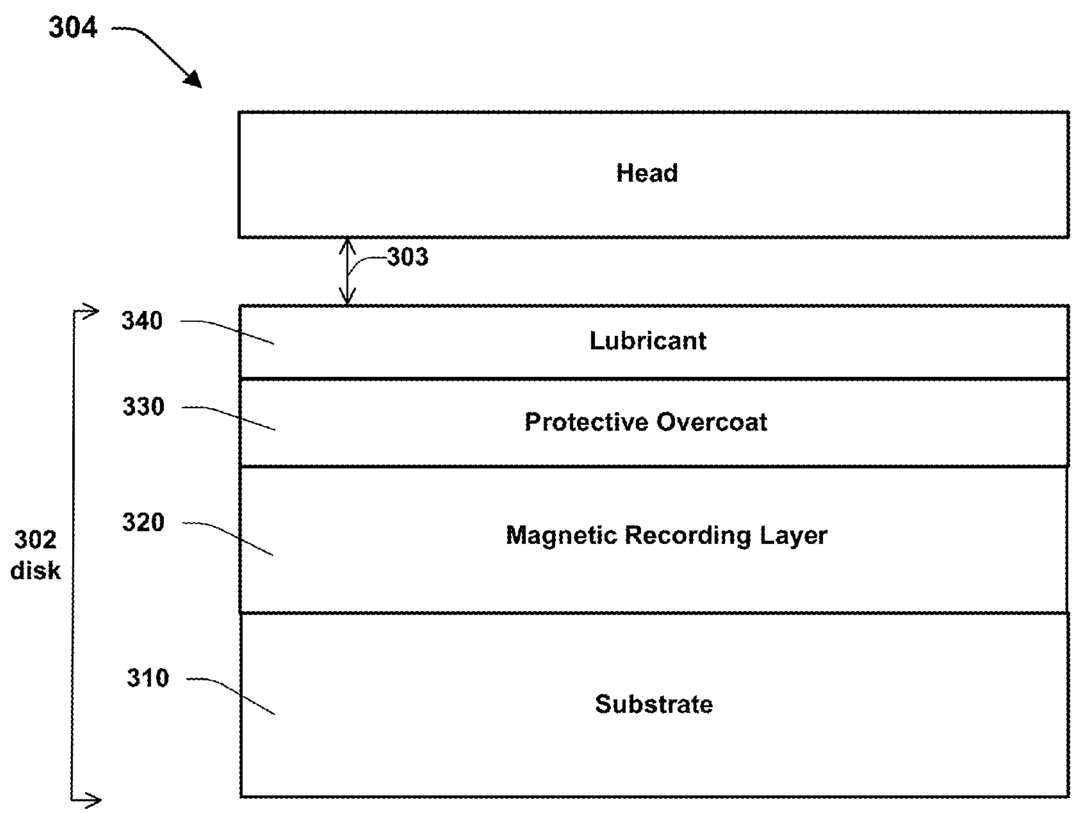
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Substrate

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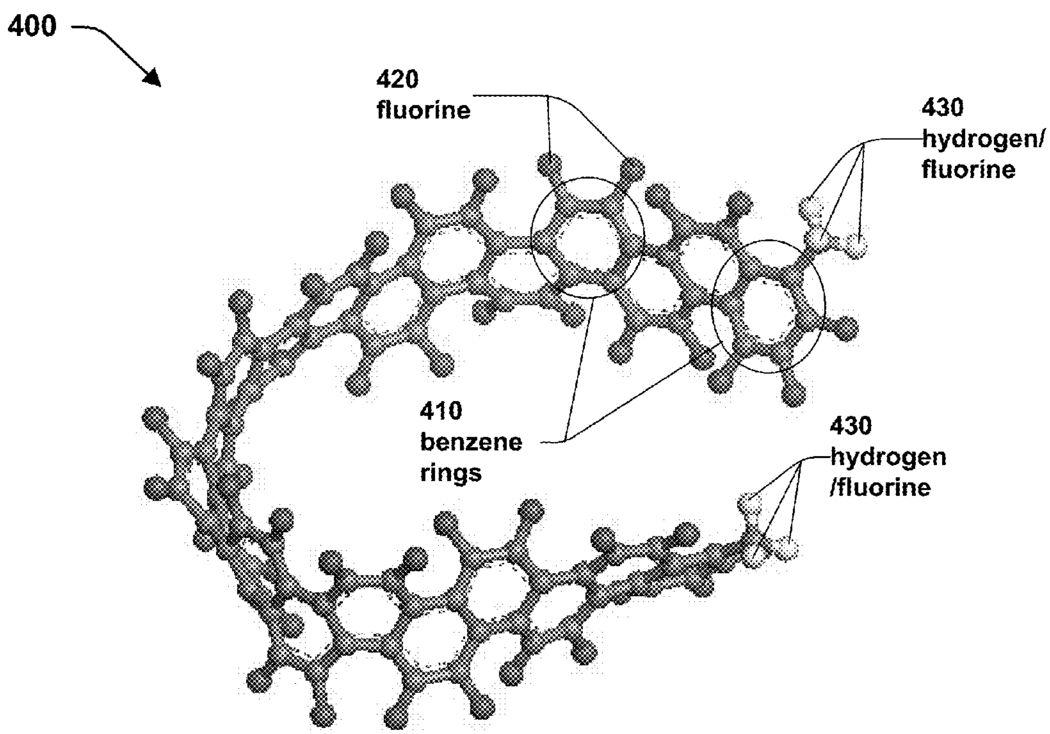
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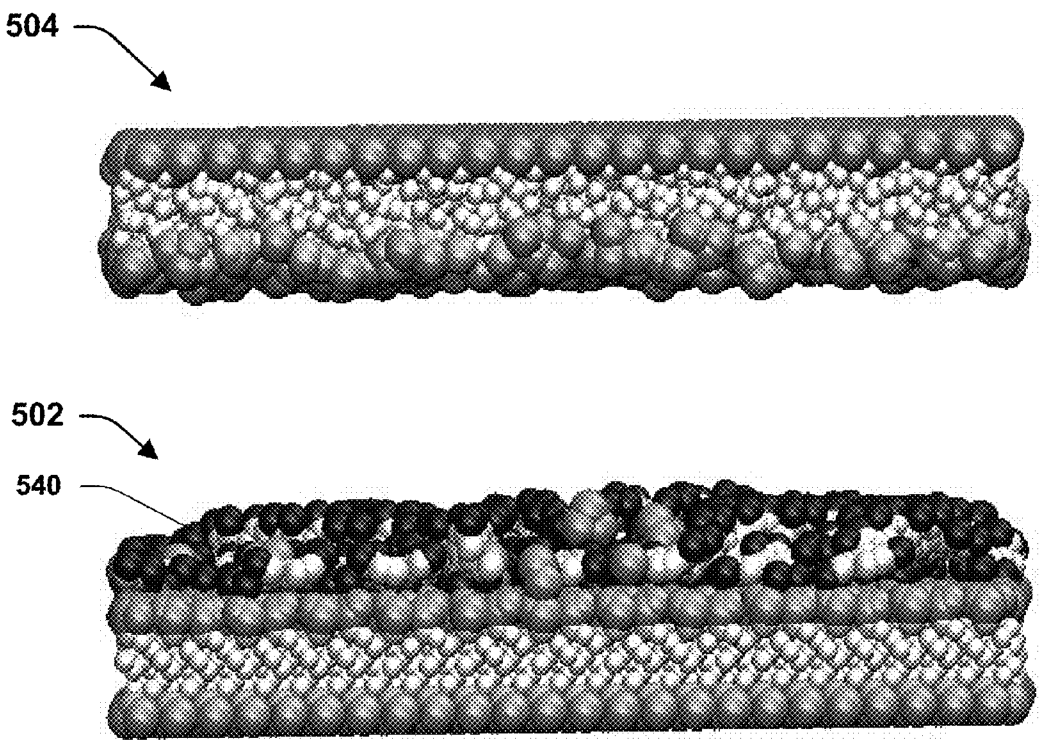
Fig. 4



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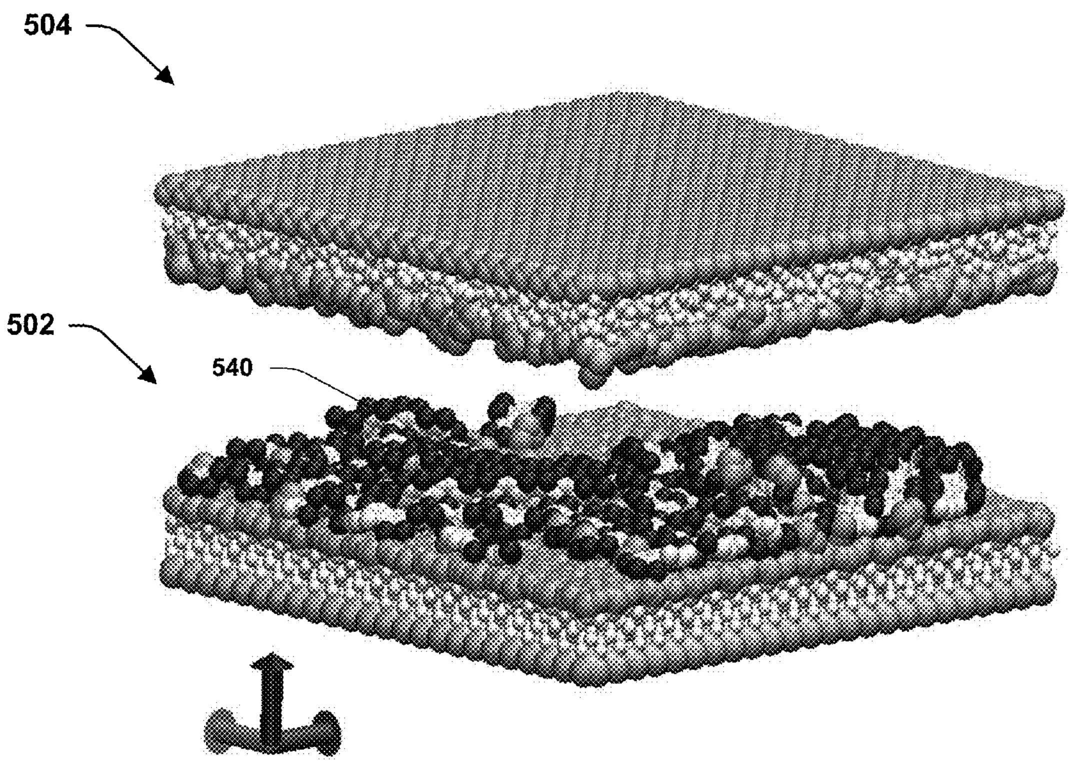

Fig. 5B

LUBRICANTS COMPRISING FLUORINATED GRAPHENE NANORIBBONS FOR MAGNETIC RECORDING MEDIA STRUCTURE

FIELD OF THE INVENTION

The present invention generally relates to lubricants for magnetic recording media and, in particular, relates to lubricants comprising fluorinated graphene nanoribbons for magnetic recording media structure.

BACKGROUND

Conventional lubricants used for magnetic recording media applications, such as Tetraol, have problems associated with the presence of —OH end groups. These problems include clustering due to interactions between end groups, a thicker lube layer due to formation of inverted U-shaped structures, thermal decomposition at high temperature at the ether bond, and lube mogul formation due to high mobility and clustering.

Some of these problems associated with conventional lubricants are illustrated in FIGS. **1** and **2**. For example, FIG. **1** illustrates the end-group clustering problem due to interactions between —OH end groups and also the normal lubrication layer thickness on the disk. FIG. **2** illustrates formation of inverted U-shaped structures resulting from the attachment of the end groups on the COC surface. Additionally, for an HAMR (Heat Assisted Magnetic Recording) system, in which the recording takes place at an elevated temperature, the surface adhesion may decrease, resulting in increases in lube mobility, lube mogul formation and lube decomposition. All of these problems contribute to a reduced reliability and performance for the hard disk drive (HDD).

BRIEF SUMMARY OF THE SUBJECT DISCLOSURE

In some aspects, the above-identified problems associated with the conventional lubricants may be eliminated or reduced by the use of fluorinated graphene nanoribbons (FGNRs) as lubricants for magnetic recording media applications.

In certain aspects, a magnetic recording media structure is provided. The magnetic recording media structure includes a substrate, a magnetic recording layer for recording information disposed over the substrate, a protective overcoat layer for protecting the magnetic recording layer disposed over the magnetic recording layer, and a lubricant layer disposed over the protective overcoat layer and comprising a fluorinated graphene nanoribbon.

In certain aspects, a method of lubricating a hard disk drive is provided. The method includes providing a magnetic recording media stack comprising a magnetic recording layer for recording information and a protective overcoat layer disposed over the magnetic recording layer and providing a lubricant layer comprising a fluorinated graphene nanoribbon on the protective overcoat layer.

In certain aspects, a lubricant for a magnetic recording media structure comprising a fluorinated graphene nanoribbon is provided.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

FIG. **1** is a diagram illustrating the end-group clustering problem due to interactions between —OH end groups associated with conventional lubricants.

FIG. **2** is a diagram illustrating formation of inverted U-shaped structures resulting from the attachment of the end groups on the COC surface associated with conventional lubricants.

FIG. **3** is a diagram depicting a HDD system comprising a magnetic recording media stack ("disk") and a magnetic read/write head ("head") according to certain aspects of the subject disclosure.

FIG. **4** is a diagram depicting one fluorinated graphene nanoribbon (FGNR) that can be used as lubricant in the magnetic recording media stack shown in FIG. **1** according to certain aspects of the subject disclosure.

FIG. **5**A is a diagram depicting a cross-sectional view of a disk with FGNR lubricant and a head according to certain aspects of the subject disclosure.

FIG. **5**B is a diagram depicting a perspective view of a disk with FGNR lubricant and a head according to certain aspects of the subject disclosure.

DETAILED DESCRIPTION

FIG. **3** is a diagram depicting a HDD system **300** comprising a magnetic recording media stack ("disk") **302** and a magnetic read/write head ("head") **304**. The head **304** is disposed above the disk **302** and separated from each other by a head-media spacing **303**. The magnetic recording media stack **302** includes a substrate **310**, a magnetic recording layer **320** for recording information, a protective overcoat **130** for protecting the magnetic recording layer **320**, and lubricant **340** for lubricating the protecting overcoat **130**. The lubricant **340** is designed to prevent a catastrophic crash when the head **304** comes in contact with the disk **302**. In certain embodiments, the protective overcoat layer **330** is carbon overcoat (COC) and has a thickness between about 0.5 and 4 nm. In some embodiments, the lubricant **340** may be directly applied to the magnetic recording layer **320**.

FIG. **4** is a diagram depicting one fluorinated graphene nanoribbon (FGNR) **400** that can be used as lubricant **340** in the magnetic recording media stack **302** shown in FIG. **3** according to certain aspects of the subject disclosure. The FGNR **400** is a narrow strip of graphene comprising a plurality of benzene rings **410** having fluorine atoms **420** attached thereto. Two benzene rings at the ends of the FGNR **400** also have hydrogen or flurorine atoms **430** attached thereto. In some embodiments, one or more of the hydrogen/fluorine atoms **430** may be replaced with any other functional groups.

In the illustrated example of FIG. **4**, the FGNR **400** is about 40 angstroms long and 7 angstroms wide and has a molecular weight of 1898 gm/mole. The FGNR **400** may be prepared at desired length and width by various methods known in the art. Some of the known methods are disclosed in U.S. Pat. No. 8,236,626, U.S. Patent Application No. 20120085991 and U.S. Patent Application No. 20120195821, each of which is incorporated herein by reference in its entirety for all purposes. In certain embodiments, depending on the number of benzene rings **410** along its length direction, the FGNR **400** can have a length between about 1 and 30 nm. In some embodiments, depending on the number of benzene rights **410** along its width direction, the FGNR **400** can have a width between about 2 and 20 angstroms.

FGNRs may be grown in situ on the protective overcoat **330** (FIG. **3**), such as carbon over coat (COC), during fabrication of the magnetic recording media stack or disk **302** or may be later applied to the surface of the COC after fabricating the disk **302**. In certain embodiments, the disk **302** is dip-coated with the FGNR molecules. With the FGNR **400** applied thereon, the surface of the protective overcoat **130** (e.g., COC) becomes frictionless. In some embodiments, the FGNRs form a lubricant film having a thickness of between about 0.5 and 3 nm.

Furthermore, the FGNR **400** has excellent electrical and thermal conductivity, which is important for HAMR applications. Thus, the FGNR **400** exhibits superior lubrication and wear resistance; and, for HAMR applications, the FGNR **400** can work as an effective heat transfer media.

Molecular dynamic simulations have been performed using LAMMPS (Large Scale Atomistic Molecular Massively Parallel Simulator, by Sandia National Lab). In the simulations, sixteen FGNRs were placed on a COC (diamond like carbon) surface. The COC surface is nitrogenated (10%) and contains 2% surface —OH group. Each of the head **304** and the disk **302** included a COC having surface dimensions of about 85×85 angstroms and about 10 angstroms thick. The head COC is a hydrogenated DLC.

After equilibrating the FGNRs on a COC disk surface for 100 ps simulation time, it was found that the FGNRs formed a uniform film on the COC surface with a better surface coverage compared to Tetraol with similar molecular weight (FIGS. **1** and **2**). FIG. **5**A and FIG. **5**B are diagrams depicting cross-sectional and perspective views, respectively, of a disk **502** with FGNR lubricant **540** and a head **504** according to certain aspects of the subject disclosure.

The simulations demonstrate that the FGNR provides a number of advantages compared to conventional lubricants. The advantages include an increased COC surface adhesion and a reduced clustering. Due to absence of C—O—C bond in its molecular structure, the FGNR also provides reduced thermal and catalytic decomposition as compared to conventional lubricants such as Tetraol. Additionally, due to absence of —OH end groups, lube clustering is reduced or eliminated. Furthermore, due to interaction of benzene rings with the COC surface, the FGNR provides a better surface adhesion resulting in a greater structural stability for the lubricant film.

The FGNR also forms a thinner film on the COC as compared to conventional lubricants such as Tetraol. In the simulations, a FGNR film having a thickness of about 8 angstroms was obtained as compared to about 14 angstroms for Tetraol or other conventional lubes with similar molecular weight. As illustrated in FIG. **3**, the conventional lubricants attach on the COC surface by the end group and form an inverted U shaped structure resulting in a thicker film and a higher head-media spacing. By contrast, as illustrated in FIGS. **5**A and **5**B, the benzene rings **410** of the FGNR **400** (FIG. **4**) lie parallel to the COC surface resulting in a thinner film and a lower head-media spacing. In the illustrated example of FIGS. **5**A and **5**B, the thinner FGNR film (8 angstroms) resulted in the head-media spacing of 27 angstroms.

Lubricants with benzene-only end groups have less clustering compared to conventional lubricants with —OH end groups. Also, since the FGNR does not contain a C—O—C group, there is lower thermal and catalytic decomposition. Interaction energy with the disk per FGNR molecule is about −6.36 kcal/molecule (negative sign indicated more attractive nature, or as cohesive energy) compared to 68.98 kcal/molecule for similar molecular weight Tetraol. Thus, the FGNR molecules have less mobility and lube clustering (lube mogul) is reduced under shear flow condition.

Accordingly, the use of FGNR as lubricant in a magnetic recording media stack can reduce or eliminate many problems associated with conventional lubricants resulting in improved reliability and performance for the HDD.

The description of the invention is provided to enable any person skilled in the art to practice the various embodiments described herein. While the present invention has been particularly described with reference to the various figures and embodiments, it should be understood that these are for illustration purposes only and should not be taken as limiting the scope of the invention.

There may be many other ways to implement the invention. Various functions and elements described herein may be partitioned differently from those shown without departing from the spirit and scope of the invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and generic principles defined herein may be applied to other embodiments. Thus, many changes and modifications may be made to the invention, by one having ordinary skill in the art, without departing from the spirit and scope of the invention.

A reference to an element in the singular is not intended to mean "one and only one" unless specifically stated, but rather "one or more." The term "some" refers to one or more. Underlined and/or italicized headings and subheadings are used for convenience only, do not limit the invention, and are not referred to in connection with the interpretation of the description of the invention. All structural and functional equivalents to the elements of the various embodiments of the invention described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and intended to be encompassed by the invention. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the above description.

We claim:

1. A magnetic recording media structure comprising:

a substrate;

a magnetic recording layer for recording information disposed over the substrate;

a protective overcoat layer for protecting the magnetic recording layer disposed over the magnetic recording layer; and

a lubricant layer disposed over the protective overcoat layer and comprising a fluorinated graphene nanoribbon, wherein the protective overcoat layer comprises a carbon overcoat (COC).

2. The magnetic recording media structure of claim **1**, wherein the magnetic recording media structure is a heat assisted magnetic recording (HAMR) media structure.

3. The magnetic recording media structure of claim **1**, wherein the protective overcoat layer has a thickness between about 0.5 and 4 nm.

4. The magnetic recording media structure of claim **1**, wherein the lubricant layer has a thickness between about 0.5 and 3 nm.

5. A magnetic recording media structure comprising:

a substrate;

a magnetic recording layer for recording information disposed over the substrate;

a protective overcoat layer for protecting the magnetic recording layer disposed over the magnetic recording layer; and

a lubricant layer disposed over the protective overcoat layer and comprising a fluorinated graphene nanoribbon, wherein the fluorinated graphene nanoribbon has a length between about 1 and 30 nm.

6. A magnetic recording media structure comprising:

a substrate;

a magnetic recording layer for recording information disposed over the substrate;

a protective overcoat layer for protecting the magnetic recording layer disposed over the magnetic recording layer; and

a lubricant layer disposed over the protective overcoat layer and comprising a fluorinated graphene nanoribbon, wherein the fluorinated graphene nanoribbon has a width between about 2 and 20 angstroms.

7. A method of lubricating a hard disk drive, the method comprising:

providing a magnetic recording media stack comprising a magnetic recording layer for recording information and a protective overcoat layer disposed over the magnetic recording layer; and

providing a lubricant layer comprising a fluorinated graphene nanoribbon on the protective overcoat layer, wherein the protective overcoat layer comprises a carbon overcoat (COC).

8. The method of claim **7**, where in the fluorinated graphene nanoribbon is grown in situ on the COC during fabrication of the magnetic recording media stack.

9. The method of claim **7**, wherein the fluorinated graphene nanoribbon is applied to the COC after the magnetic recording media stack has been fabricated.

10. The method of claim **9**, wherein the magnetic recording media stack is dip-coated with the fluorinated graphene nanoribbon.

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